

# Central exclusive production in the ALICE experiment at the LHC

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## Abstract

The ALICE experiment at the Large Hadron Collider (LHC) at CERN consists of a central barrel, a muon spectrometer and additional detectors for trigger and event classification purposes. The low transverse momentum threshold of the central barrel gives ALICE a unique opportunity to study the low mass sector of central exclusive production at the LHC.

Keywords: ALICE experiment; exclusive production; gluon shadowing.

## 1 Introduction

The ALICE experiment at CERN consists of a central barrel and of a forward muon spectrometer[1]. Additional detectors for trigger purposes and event classification exist outside of the central barrel. Such a geometry allows the investigation of many properties of diffractive reactions at hadron colliders, for example the measurement of single and double diffractive dissociation cross-sections and the study of central exclusive production (CEP). The ALICE experiment has taken data in proton-proton, proton-lead as well as lead-lead collisions in Run I at the Large Hadron Collider (LHC).

## 2 The ALICE Experiment

In the ALICE central barrel, momentum reconstruction and particle identification are achieved in the pseudorapidity range  $-1.4 < \eta < 1.4$  by combining the information of the Inner Tracking System (ITS) and the Time Projection Chamber (TPC). In the pseudorapidity range  $-0.9 < \eta < 0.9$ , the information from the Transition Radiation Detector (TRD) and the Time-of-Flight (TOF) system is also available. A muon spectrometer covers the range  $-4.0 < \eta < -2.5$ . At very forward angles, the energy flow

is measured by Zero Degree Calorimeters (ZDC)[2]. Detectors for event classification and trigger purposes are located on both sides of the ALICE central barrel. First, the scintillator arrays V0A and V0C cover the pseudorapidity range  $2.8 < \eta < 5.1$  and  $-3.7 < \eta < -1.7$ , respectively. The four- and eight-fold segmentation in pseudorapidity and azimuth result in 32 individual counters in each array. Second, a Forward Multiplicity Detector (FMD) based on silicon strip technology covers the pseudorapidity range  $-3.4 < \eta < -1.7$  and  $1.7 < \eta < 5.1$ , respectively. Additional scintillator arrays ADA and ADC are being built for data taking in Run II, with pseudorapidity coverage of  $-7.0 < \eta < -4.8$  and  $4.7 < \eta < 6.3$ , respectively.

### 3 Central Production in ALICE

Central diffractive events are experimentally defined by activity in the central barrel and by no activity outside the central barrel. This condition can be implemented at trigger level zero (L0) by defining barrel activity as hits in the ITS pixel detector (SPD) or the TOF system. The gap condition is realized by the absence of V0 signals, hence a gap of two units in pseudorapidity on either barrel side can be defined at L0. In Run II, the additional detectors ADA and ADC will further enhance the L0 gap trigger capabilities as described above. In the offline analysis, the information from the V0, FMD, ITS and TPC detectors define the gaps spanning the range  $-3.7 < \eta < -0.9$  and  $0.9 < \eta < 5.1$ . Events with and without detector signals in these two ranges are defined to be no-gap and double-gap events, respectively. A rapidity gap can be due either to Pomeron, Reggeon or photon exchange. A double-gap signature can therefore be induced by a combination of these exchanges. Pomeron-Pomeron events result in centrally produced states with quantum numbers  $C = +1$  ( $C = C$ -parity) and  $I = 0$  ( $I =$  isospin). The corresponding quantum numbers in photon-Pomeron induced events are  $C = -1$  and  $I = 0$  or  $I = 1$ [3]. Exclusive particle production in proton-proton collisions is dominated by Pomeron-Pomeron interactions, whereas photon-photon and Pomeron-photon exchanges dominate in lead-lead collisions. The systematics of Pomeron and photon interactions can therefore be studied by analyzing proton-proton, proton-lead and lead-lead collisions.

### 4 Central Meson Production in Proton-Proton Collisions

In the years 2010-2011, ALICE recorded zero bias and minimum bias data in pp-collisions at a center-of-mass energy of  $\sqrt{s} = 7$  TeV. The zero bias trigger was defined by beam bunches crossing at the ALICE interaction point, while the minimum bias trigger was derived by minimum activity in either the ITS pixel or the V0 detector. Events with double-gap topology as described above are contained in this minimum bias trigger, hence central diffractive events were analyzed from the minimum bias data sample.

For the results discussed below,  $3.6 \times 10^8$  minimum bias events were analyzed. First, the fraction of events satisfying the gap condition described above was calculated. This fraction was found to be about  $2 \times 10^{-4}$ . Only runs where this fraction was calculated to be within  $3\sigma$  of the average value of the corresponding distribution were further analyzed. This procedure resulted in about  $7 \times 10^4$  double-gap events. As a next step, the track multiplicity in the pseudorapidity range  $-0.9 < \eta < 0.9$  was evaluated. Very low transverse momentum tracks never reach the TPC which results in events with track multiplicity zero. The multiplicity distributions of the double- and no-gap events clearly show different behavior as discussed in Ref. [4].

The specific energy loss  $dE/dx$  as measured by the TPC in combination with the TOF detector information identifies pions with transverse momenta  $p_T \geq 300$  MeV/c. The events with exactly two pions are selected, and the invariant mass of the pion pairs is calculated. These pion pairs can be of like- or unlike-sign charge. Like-sign pion pairs can arise from two-pion pair production with loss of one pion of same charge in each pair, either due to the low  $p_T$ -cutoff described above, or due to the finite pseudorapidity coverage of the detectors used for defining the rapidity gap. For charge symmetric detector acceptances, the unlike-sign pairs contain the signal plus background, whereas the like-sign pairs represent the background. From the two distributions derived in the analysis, the background is estimated to be less than 5%. The particle identification by the TOF detector requires the single-track transverse momentum  $p_T$  to be larger than about 300 MeV/c. This single-track  $p_T$ -cut introduces a significant acceptance reduction for pair masses  $M(\pi\pi) \leq 0.8$  GeV/c<sup>2</sup> at low pair- $p_T$ . In the no-gap events, structures are seen from  $K_s^0$ - and  $\rho_0$ -decays. Two additional structures are associated with  $f_0(980)$ - and  $f_2(1270)$ -decays. In the double-gap distribution, the  $K_s^0$  and  $\rho_0$  are highly suppressed while the  $f_0(980)$  and  $f_2(1270)$  with quantum numbers  $J^{PC} = (0,2)^{++}$  are much enhanced[5]. This enhancement of  $J^{PC} = (\text{even})^{++}$  states is evidence that the double gap condition used for analysing the minimum bias data sample selects events dominated by double Pomeron exchange.

## 5 Central Meson Production in Lead-Lead Collisions

Heavy-ion and proton beams at high energies are the sources of strong electromagnetic fields. These fields can be represented by an ensemble of equivalent photons by identifying the Poynting vector of the electromagnetic field with the corresponding quantity of the photon ensemble[6, 7]. Cross-sections of heavy-ion and proton-induced photon-photon processes at high energies can subsequently be calculated by folding the respective photon flux with the elementary photon-photon cross-section taking into account the electromagnetic form factor[8, 9, 10, 11, 12]. The photon flux associated with the heavy-ion electromagnetic field scales with the nuclear charge squared, hence large cross-sections for heavy-ion induced

electromagnetic and photonuclear processes result. Of particular interest is exclusive photoproduction of vector mesons in heavy-ion collisions. The vector meson production cross-section depends on the nuclear gluon distribution, hence allows the study of nuclear gluon shadowing effects at values of Bjorken- $x \sim 10^{-3}$  and  $\sim 10^{-2}$  for data taken in the ALICE central barrel and the muon spectrometer, respectively.

During the heavy-ion runs in 2010 and 2011, special triggers were implemented to filter out gap topologies. In the 2011 run, a trigger to select forward produced  $J/\psi$  consisted of a single muon trigger in the muon spectrometer, of at least one hit in the V0C detector, and of no hit in the V0A detector. The one hit in V0C is required due to the large overlap of V0C with the muon spectrometer acceptance. With this trigger, a sample of  $3.16 \times 10^6$  events was collected. The analysis of this data sample with further requirements such as track matching between muon trigger chambers and tracking chambers, of two reconstructed muons of opposite charge, and of restricting the di-muon rapidity to the range  $-3.6 < y < -2.6$  reduces the data sample to 3209 events which prominently show the  $J/\psi$  mass peak in the invariant mass spectrum[13]. The  $J/\psi$  cross-section derived in this ALICE analysis is best produced by models which include nuclear gluon shadowing consistent with the EPS09 or EPS08 parametrizations.

In addition, a trigger to select  $J/\psi$  at mid-rapidity was implemented. Activity in the central barrel was required by at least two hits in the SPD of the ITS, a number of TOF pads  $N^{TOF}$  with signal  $2 \leq N^{TOF} \leq 6$ , with at least two of them with a difference in azimuth  $\Delta\phi$  in the range  $150^\circ \leq \Delta\phi \leq 180^\circ$ . The back-to-back condition applied to the TOF signals effectively restricts the final state invariant mass to values  $\geq 2 \text{ GeV}/c^2$ . The absence of V0 signals is required for the gap condition. With this trigger, a data sample of about  $6.5 \times 10^6$  was taken. The analysis of this data sample with further requirements such as reconstructed primary vertex, only two good tracks with tighter quality cuts with at least one of them with  $p_T \geq 1 \text{ GeV}/c$ , and two track invariant mass in the range  $2.2 < M_{inv} < 6 \text{ GeV}/c^2$  reduces the data sample to 4542 events. The  $dE/dx$  distribution derived from the TPC information clearly separates the muon pairs from the electron pairs. The background contained in the data can be estimated from the like-sign pair distribution. The unlike-sign pair mass distribution clearly shows the  $J/\psi$  mass peak in both the electron and the muon decay channel. The cross-section derived in this analysis is found to be in good agreement with the model which includes the EPS09 parametrization of nuclear gluon shadowing[14].

## 6 Conclusions

The ALICE experiment has analysed exclusive particle production in proton-proton and lead-lead collisions in Run I of the LHC. The comparison of properties of double-gap events with no-gap events clearly demonstrates the justification of such an approach. Further studies are under way for identifying the remaining background, and for establishing algorithms for further background reduction. Dedicated triggers implemented

in the heavy-ion run combine the special characteristics of the exclusively produced tracks with the gap topology of the event. The analysis of these events establishes the identification of  $J/\psi$ -decays, both in the ALICE central barrel and in the forward muon spectrometer. New detector arrays ADA and ADC will increase the pseudorapidity coverage considerably in Run II.

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